Ecology of the desert kit fox (*Vulpes macrotis arsipus*) in Chuckwalla Valley, California

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Abstract

The desert kit fox (*Vulpes macrotis arsipus*) is an uncommon to rare inhabitant of the Mojave and Colorado deserts in California. This previously low-key subspecies is now being threatened by a suite of direct and indirect impacts due to the rapid increase in large-scale industrial renewable energy development in important habitat areas. This study attempts to assess habitat selection by desert kit foxes in Chuckwalla Valley, CA, in the context of the increasing presence of solar energy project sites in the area.

An Unmanned Aerial System (UAS) was used to assess desert kit fox burrow and vegetation density from aerial imagery, and line-transect surveys were conducted to assess desert kit fox scat, prey, and predator densities. The presence of localized land development and an existing Habitat Suitability Index were assessed using GIS. The relationship between these variables and the desert kit foxes was assessed by fitting Generalized Linear Models. I found that ecological predictors of desert kit fox habitat occupancy gauged by burrow density can contradict those of habitat use gauged by scat density. Thus, habitat suitability and habitat connectivity may be impacted differently by land development. Proximity to development directly influenced habitat occupancy and use models as well. The Habitat Suitability Index based on widely accepted desert kit fox ecology was strongly contradicted by regression results and individual observations. In addition, coyote presence was found to negatively impact habitat occupancy and use, which suggests that water availability associated with land development may indirectly impact desert kit foxes. I conclude that current knowledge and the assumptions of cumulative impacts of land development are inadequate for the assessment of the impacts of large-scale renewable energy development in desert kit fox habitat.

1 CONTENTS

2 INTRODUCTION

The desert kit fox (*Vulpes macrotis arsipus*) is an uncommon to rare inhabitant of the Mojave and Colorado deserts in California (CEC 2012). The subspecies has historically been broadly distributed across the California desert where it relies on sparsely vegetated scrub habitats such as creosote bush (*Larrea tridentata*) scrub communities that support abundant rodent populations (McGrew 1979). The desert kit fox has not been subject to assessment or monitoring efforts due to the assumption that its desert habitat would remain undeveloped and populations would remain stable. However, they are now being threatened by a suite of direct and indirect impacts due to the rapid increase in large-scale industrial renewable energy development in important habitat areas. This study attempts to gather information about the utilization of habitat by desert kit foxes in Chuckwalla Valley, CA, in the context of the increasing presence of solar energy project sites in the area.

2.1 NATURAL HISTORY

In the California desert region, desert kit fox populations are closely associated with creosote bush scrub communities (McGrew 1979). Kit foxes are semifossorial and primarily nocturnal, residing in subterranean dens with typical keyhole shaped entrances. They generally require require friable soils with little or no relief for excavating dens which they use throughout the year for cover, thermoregulation, water conservation, and raising young (CEC 2012). Kit foxes prefer the presence of short, patchy vegetation in their denning habitat (Egoscue 1962, O'Farrell and Gilbertson 1986). Kit foxes are also able to adapt to open habitats including creosote flats and grasslands (Rodrick and Mathews 1999). Egoscue (1962) suggested kit foxes can also utilize sandy dune habitat for foraging.

Figure 1: Typical creosote bush scrub at study site

Movement

Kit foxes are almost entirely nocturnal, and daytime activity is confined to the vicinity of the den (Egoscue 1956). The first account of the movement of desert kit foxes recorded the maximum foraging distance from the den as two miles (Grinnell 1937). Nightly movements vary with seasonality and rodent abundance (Egoscue 1956). In Western Arizona, male and female desert kit foxes traveled a mean of 14.3 and 11.8 km per night respectively (Zoellick et al. 1989). Although nightly foraging distance is greater in males than females, home range sizes between sexes do not differ, with estimates of home range varying from 251 ha to 1,160 ha (Cypher 2003 in Meaney et al. 2006). Difference in the size of home ranges may be related to food availability (Spiegel 1996).

Foraging Ecology

Kit foxes are "opportunistic primary, secondary and tertiary consumers and scavengers, likely regulated by prey abundance" (Cypher 2003 in Meaney et al. 2006). The primary prey of kit foxes are kangaroo rats (*Dipodomys* spp.) that are locally abundant. Several authors have emphasized the correlation between the ecological and geographical distribution of kit foxes and *Dipodomys* spp. (Meaney et al. 2006). Merriam's Kangaroo rat (*Dipodomys merrami*) is the primary prey of the desert kit fox in the Californian Desert (NPS 2012). Kit foxes are opportunistic feeders to some extent; however, studies have found no evidence of switching to diurnal prey or moving to areas of greater abundance of secondary prey when experiencing a decline in primary prey species (Meaney 2006).

Other common prey species include leporids (rabbits and hares), rodents, and insects. Kit foxes also consume birds, reptiles, carrion, and rarely, plant material such as cactus fruits (List and Cypher 2004). Kit foxes are known to cache food and consume anthropogenic food (Cypher 2003).

2.2 THREATS

Disease

Kit foxes are susceptible to infection by numerous diseases and parasites; however, only a few diseases, such as rabies and canine distemper, can produce population level impacts (Cypher 2003 in Meaney et al. 2006). Although disease is typically not a major source of mortality in kit foxes in California, there have been several instances of viral diseases causing catastrophic declines in Island foxes and San Joaquin kit foxes (White et al. 2000, Coonan 2003).

In late 2011, an outbreak of canine distemper emerged in the desert kit fox population at the Genesis solar project site in the Mojave Desert (Clifford et al. 2012). The exact cause of the outbreak is still unknown. A veterinarian at the California Department of Fish and Game suggests that the two most likely reasons are either the introduction of a virulent strain of the virus by domestic dogs or other carnivores, or stress caused by the construction activity at Genesis that made the foxes more susceptible to full-blown cases of distemper (Sahagun 2012).

Roads

Urbanization and industrial development of the California desert region presents a growing risk to desert kit fox populations. Vehicle strikes were found to be a significant cause of mortality in kit foxes in a desert valley in Utah as far back as 1962 (Egoscue 1962). Cypher et al. (2009) studied the effects of two-lane roads on kit foxes in California and found no evidence of road avoidance or an impact on population demography and ecology.

Predation

Larger predators such as wolves and coyotes almost always co-occur with foxes, and kit foxes are usually subject to intense interference competition and exploitative competition from coyotes in particular (Cypher 2003). There is substantial overlap in the diets of coyotes and San Joaquin kit foxes, indicating a high potential for resource competition which may be amplified by low mammalian prey availability during droughts (White et al. 1995). The interaction between coyotes and desert kit foxes over common prey in the Californian desert has not been studied. Low food availability may result in reduced adult survival of kit foxes if individuals are forced to forage for longer periods and greater distances, which increases the risk of mortality from predation and other sources (Cypher 2003 in Meaney et al. 2006). Desert kit foxes generally meet their water requirements through consumption of food, however coyotes are able to compete in new areas because of increased water availability related to new development since they depend on free water.

Renewable Energy

Habitat loss and fragmentation from the rapid expansion of large-scale industrial solar and wind energy development in the Mojave and Colorado Deserts pose a current and growing threat to the desert kit fox. Since 2007, almost 39,000 acres of solar energy projects in the Mojave Desert have been approved, most of which are under construction, and an additional 30,622 acres of solar energy projects are in review (Kadaba et al. 2013). In addition, the public lands within the range of the desert kit fox in California currently have eighteen pending applications for solar energy projects and transmission lines, totaling over 96,000 additional acres spread throughout the desert kit fox's range (Ibid).

These large-scale industrial energy developments, including associated transmission lines and roads, have a range of direct and indirect impacts on the desert kit fox, and do not properly consider or mitigate for impacts on the desert kit fox. Key threats from large-scale industrial solar development to the desert kit fox include habitat loss, degradation, fragmentation, and loss of connectivity, as well as direct and indirect impacts resulting from reduced ability for movement, increased competition and depredation, increased in non-native cover, mortality from roads, and displacement of foxes from den sites (Ibid). The scale of the impact of these threats on kit fox populations have not been evaluated so far.

2.3 Population Trends

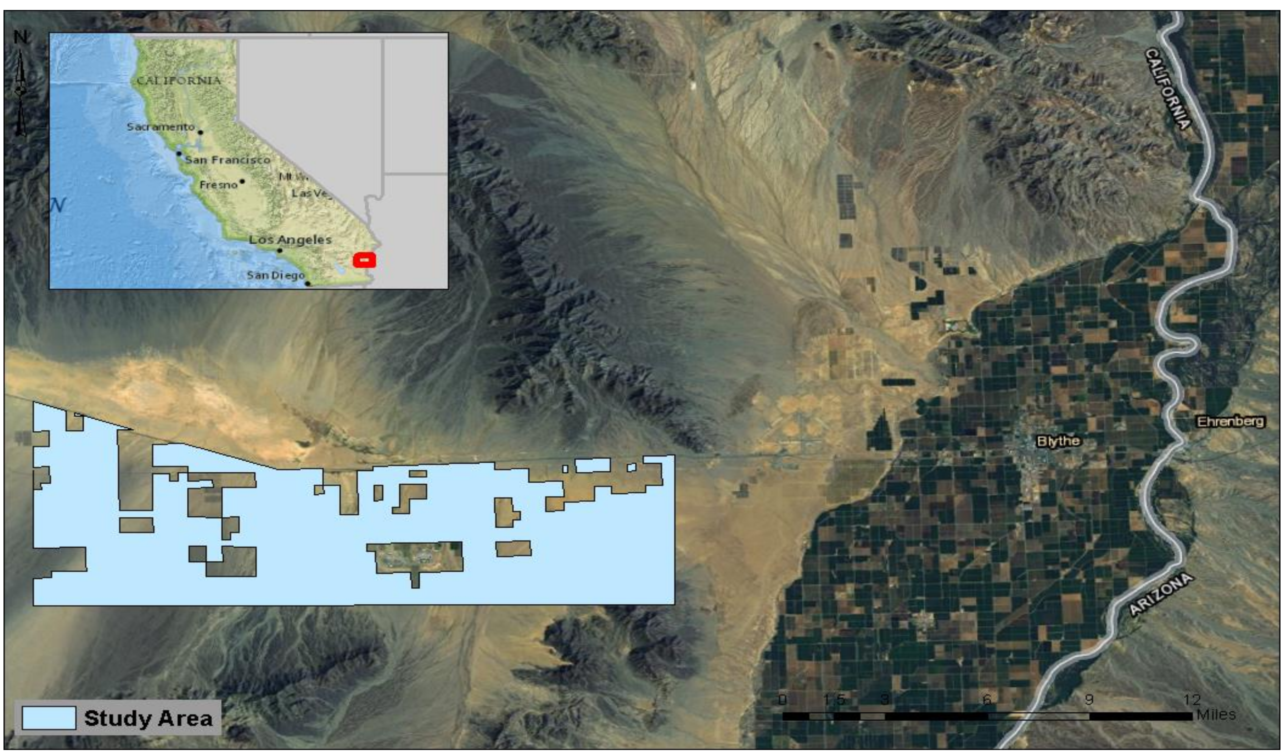
Due to the lack of population monitoring, population trends for the desert kit fox in California are unknown. However, the desert kit fox is considered an "uncommon to rare permanent resident of arid regions of the southern portion of California" (CEC 2012). The loss, degradation, and fragmentation of desert kit fox habitat have been increasing, particularly in recent years, due to accelerating industrial energy development in important habitat areas, combined with off-road vehicle use, grazing, agriculture, military uses, urbanization, and anthropogenic climate change (Kadaba et al. 2013). The accelerating loss of habitat is likely to be contributing to population declines across the range, concentrated in regions with the greatest habitat impacts. The impact to the desert kit fox population that experienced a local die-off in 2011 and 2012 due to a canine distemper outbreak around the Genesis Solar energy development site in Riverside County is unknown.

3 Study Area

The study area is located in Chuckwalla Valley, in Riverside County, California. The valley is in the Mojave-Sonoran transition desert region in the Colorado Desert. It is bound by the Chuckwalla Valley mountain range to the south, and several distinct mountain ranges to the north, including Eagle mountains, Palen mountain, and McCoy mountain. The major geological features of the valley can be described as washes and desert pavement within broad alluvial-fan bajadas, with Aeolian sand found in the East of the valley, and increasingly rocky areas found toward the West. Playas are also present, Ford Dry Lake being the largest in the area. The climate can vary drastically annually – in nearby Blythe, CA. the average rainfall is 3.83 inches, with the most precipitation received during August and September. The valley is susceptible to flooding during monsoon rains. In Blythe, the average minimum is 3.8°c, and average maximum is 42.7°c. Maximum temperatures frequently cross 48.8°c (120°F) during the summer in the valley. Creosote bush scrub dominates the valley, with white bursage *(Ambrosia dumosa)*, big galleta grass (*Pleuraphis rigida)*, desert ironwood (*Olneya tesota*), palo verde (*Parkinsonia microphylla*), mesquite(*Prosopis* spp.), catclaw acacia (*Senegalia greggii),* ocotillo *(Fouquieria splendens*), several species of cholla cacti, and invasive Sahara mustard (*Brassica tournefortii*) and Russian thistle (*Kali tragus*) commonly occurring. Interstate-10 cuts across the valley running in the East-West direction. Commonly found fauna are Black-tailed jackrabbits (*Lepus californicus*), Desert cottontails (*Sylvilagus audubonii*), kangaroo rats (*Dipodomys* spp.), zebra-tailed lizards (*Callisaurus draconoides*), western whiptail lizards (*Cnemidophorus tigris*), desert kit foxes, coyotes (*Canis latrans*), sidewinders (*Crotalus cerastes*), mourning doves (*Zenaida macroura*), and loggerhead shrikes (*Lanius ludovicianus*). Bobcats (*Lynx rufus*), mule deer (*Odocoileus hemionus*), burrowing owls (*Athene cunicularia*), desert horned lizards (*Phrynosoma platyrhinos*), desert tortoise (*Gopherus agassizii*), and Mojave fringe toed lizards (*Uma scoparia*) also occur in the valley.

The study area was narrowed to a perimeter that stretched from 18.4 km west to 46.2 km west of the town of Blythe, where the field team was based, and was restricted between Interstate-10 to the north and the Chuckwalla mountain range to the south.

Figure 2: Study area located in Chuckwalla Valley, CA



This location included areas where kit foxes were affected by the canine distemper outbreak originating at the Genesis solar project, which is 2.5 km North of the northern edge of the study perimeter. Significant features contained within the study area are the Chuckwalla Valley State Prison, the Devers-Palo Verde No.2 Project (DPV2) transmission line and associated access roads (Power Line road), the Colorado River Substation and associated access road, Wiley's Well Road, Chuckwalla Valley road, Graham Pass road, Augustine Pass road, and several parcels of land owned partially or wholly by the Department of Energy,. A majority of the land within this perimeter is owned by the Bureau of Land Management (BLM), and the locations chosen for survey were located on this land. Similarly, a vast majority of renewable energy projects in the Southwest are planned on land owned by the BLM.

4 STUDY ELEMENTS

The study attempted to quantify several ecological characteristics of desert kit fox habitat, summarized in the table below.

Table 1: Elements related to desert kit fox habitat selection, their hypothesized relationship with desert kit foxes, and the methods used to evaluate them.

Characteristic		Relationship with kit foxes	Unit	Method
Desert kit fox	Habitat occupancy	N/A	Burrow density	Aerial survey
Creosote bushes	Abundance	Food Availability	Density	Aerial Survey
Merriam's kangaroo rat	Abundance	Food availability	Density	Visual encounter survey (Individuals)
Other rodents	Abundance	Food availability	Density	Visual encounter survey (Individuals)

Leporids	Abundance	Food availability	Density	Visual encounter survey (Individuals)
Reptiles and invertebrates	Abundance	Food availability/Habitat type proxy	Density	Visual encounter survey (Individuals)
All species	Mortality	N/A	Count	Visual encounter survey (Individuals)
Desert kit fox	Habitat use	N/A	Scat density	Visual encounter survey (Scat)
Coyote	Habitat use	Predation/Competition	Scat density	Visual encounter survey (Scat)
Distance to development	Linear distance	Habitat modification	Kilometers	Geospatial Analysis
Habitat suitability	Suitability Index	Habitat suitability	N/A	Geospatial Analysis

Other methods were piloted but not pursued fully – Scent-baited camera traps, rodent traps, pit-fall traps, and spotlighting for eyeshine. They are briefly discussed later.

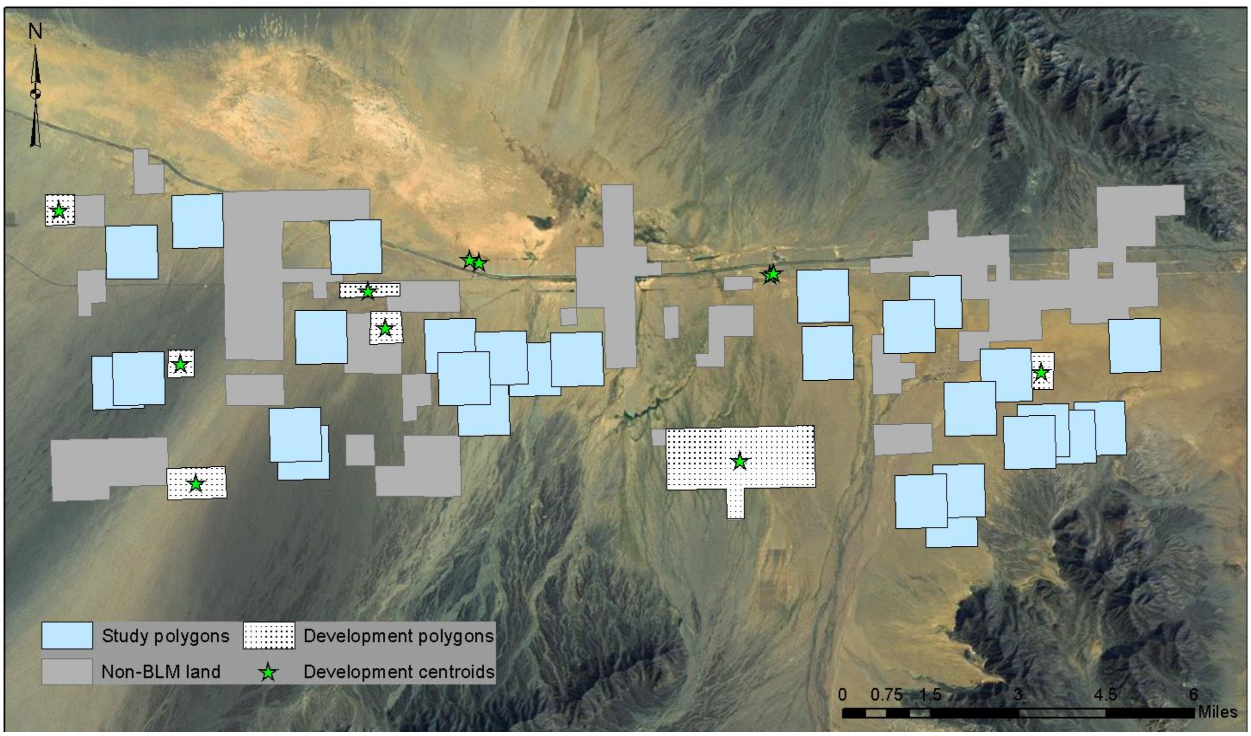
5 METHODS

5.1 CHOOSING SURVEY PLOTS

Survey effort was divided into fewer large size plots rather than many smaller plots, since burrows can be very rare in the study area and small study units in such a large valley would not be able to efficiently evaluate a sparse population. Each study unit was formed by a 2 sq. km square-shaped plot, as this was found to be close to the maximum area that could be surveyed by the Unmanned Aerial System (UAS) setup used for aerial surveys in one day.

The survey plots were selected in ArcMap 10 (ESRI 2011). A perimeter was drawn around the area of interest, ensuring the maximum hiking distance from a road was 5 kilometers. Areas not owned by the BLM were excluded, and a 1 km buffer was created around the edges of the perimeter (including the islands of parcels not owned by BLM). 32 random points were generated using the Create Random Points Tool, which served as the centroid of the 32 survey plots. 3 plots close to Chuckwalla Valley State Prison had to be discarded due to safety concerns. An additional point was discarded due to incomplete data collection. The final 28 plots represented in this study are pictured in the figure below.

Figure 3: 28 study plots located on land owned by the Bureau of Land Management (BLM), interspersed with localized areas of development and non-BLM land.



5.2 AERIAL SURVEYS

The aerial survey method was developed under several influencing conditions – the recent outbreak of infectious disease motivated non-invasive surveys for fox sign, and the relative rarity of fox burrows in the Chuckwalla valley meant a huge amount of observer effort must be made for the detection of a significant amount of burrows. Aerial imagery captured by Unmanned Aerial Systems (UASs) – popularly referred to as drones - were the most efficient available survey method for this study.

A quadcopter UAS allowed steady, low altitude flight. The UAS setup consisted of the following: 3DR ArduCopter (C Frame) (2 units), Spektrum DX7s RC, 3DR radio telemetry, and 3 cell 4000, 4500, and 5000 mAh LiPo batteries. Both quadcopters ran on the APM 2.6 autopilot system, also developed by 3D Robotics. This is an open source autopilot system which is complementary to the open source software – Mission Planner 1.2 – used to program the quadcopters' flight paths (Oborne 2013). Other necessary field UAS accessories included Kestrel pocket weather tracker and tablet computer.

Figure 4: Quadcopter used for aerial surveys of desert fox burrow and vegetation density

5.2.1 Camera modifications

Survey video was captured using a 4MM modified Gopro HD Hero 3: White Edition Night Vision Full Spectrum infrared camera, sold by RageCams. It was mounted under the forward facing portion of the base board of the quadcopter with an adhesive mount, and housed in a skeleton case to protect from dust and crashes. The GoPro Hero 3 was chosen because of its light weight, wide angle lens, and adequate resolution.

GoPro Hero 3 cameras automatically shut off when they reach 51.6°c. It was necessary to power the camera through external power via USB, with the regular battery removed. The absence of heat from the battery as well as the ventilation facilitated by the empty battery cavity allowed the camera to function in higher temperatures without failures. A regular GoPro running off its original batteries usually failed after 15 or 20 minutes under field conditions that rarely remained below 29.4°c. The externally powered GoPro was powered by the quadcopter's battery, which conveniently did not require multiple battery changes in the field and avoided accidental mid-flight battery discharges. The modified RageCam lens also avoided the fish eye effect obtained with stock GoPro cameras, while providing a realistic view of depth and maintaining a wide angle.

5.2.2 Development of flight parameters

The flight parameters were worked out through field tests. The kit fox burrows incidentally found during a training period of the study were used to calibrate the flight parameters.

Altitude and speed: While testing a range of altitudes over incidentally found burrows, an altitude of 15 meters maximized the area captured in one frame while still capturing burrow entrances at a resolution that allows easy identification, and avoided the tallest trees. Various speeds were also tested, and the ideal speed was 7.5 m/s.

Flight pattern: The appropriate flight pattern was determined by placing flags in a line at 10 meter intervals. The UAS was flown perpendicular to the flag line at an altitude of 15 meters, which determined each frame captured a distance 25 meters to the right and left of the camera. Thus each grid line was placed 50 meters apart in the survey flight paths.

Grid pattern: The grid pattern was determined by the maximum flight time allowed by each battery, while the battery was determined by the maximum payload capacity of the UAS. Battery consumption spiked when the quadcopter executed turns, so a fewer number of longer grid lines allowed a greater area to be covered on a single battery. Additionally, some buffer time was allowed for battery life that would diminish with use and hot temperatures, as well as allowing the quadcopter to travel to more survey grids from a single launch point. Considering all these factors, grids were designed to be 714.5 meters long and 200 meters wide. This grid pattern allowed 2 square kilometers to be surveyed using 14 grids.

Figure 5: Typical mission grid in Misson Planner 1.2 mav 10 software. 14 similar grids were plotted on each of the 2 sq. km. study plots for aerial surveys.

Mission planning: Missions were planned using Mission Planner 1.2.54 mav 10 software (Oborne 2013). I began by importing the coordinates of the northeastern vertex of a plot. This served as the top right corner of the first grid, from which I completed the 714.5 x 200 meter grid using the Distance from home/Distance from previous display in the Flight Planner screen. Then a polygon was drawn on the perimeter of the grid using the Draw Polygon tool. Gridlines were automatically generated by the Grid option of the AutoWP tool, which uses the polygon as a perimeter. This tool requires Relative Altitude (15 m), Distance between lines (50 m), Distance between waypoints (40 m), and line direction (0-180 degrees, depending on the location of the launch site) as input. The other 13 grids were created similarly, and all 14 missions were saved for use in the field. The coordinates of the center of a set of 6 grids and a set of 8 grids were located using the Mission Planner software, and these were used as launch sites.

Mission execution: The launch sites were reached using a GPS unit programmed with their coordinates. A tent ground cover was set up as a launch pad to prevent sand from being stirred up and settling in parts of the quadcopter during take-off. The Kestrel pocket weather tracker was tied to a bush and turned on to monitor weather. A sun shade was tied to a bush to shade the batteries and spare quadcopter, which proved to be vital to prevent malfunctions. A small ultra-bright tablet was essential to have the flight parameter screen visible in bright sunlight.

Weather limitations: Heat caused Electronic Speed Controllers (ESCs) to fail. The weather constraints to prevent UAS failure were 40°c in morning or evening sun, and 37°c in harsh mid-day sun. 8 kilometers per hour is the maximum wind speed (crosswind, headwind, or tailwind) for stable flights and videos.

5.2.3 Burrow survey:

Videos were downloaded and reviewed for the presence of desert kit fox burrows. I trained in burrow identification by capturing test video over known burrows during the training period. I identified burrows on the basis of diagnostic signs indicating desert kit foxes – entrances that are generally longer than wider, and long, straight aprons (seen in figure 6).

Both Burrow complexes and individual burrows were recorded as single units. Only burrows displaying clear diagnostic signs were recorded. Ambiguous burrows were not recorded or included in any analysis. Multiple species burrow complexes with signs of desert kit foxes as well as badgers were not included in any analysis. Burrow locations were noted by matching the video time stamp with the programmed flight plan.

Figure 6: Burrows and burrow complexes

B. Aerial image of a burrow complex that includes the burrow pictured to the left (circled in red)

A. An active desert kit fox burrow photographed from the ground

C. Multispecies burrow complex with signs of desert kit foxes and badgers

5.2.4 Vegetation survey

Aerial video was also used to enumerate creosote bushes on each study plots. Every alternate video (7 out of 14) of each study plot was imported into Adobe Premiere Pro CC software *(*Adobe Systems Incorporated 2013*),* and a transparent horizontal band that is 10% the width of the frame was overlaid in the center of the frame in all imported videos (seen in figure 7). This covered 0.007 sq km of every 2 sq km square plot. Creosote bushes under this band were easily visually identified and counted – yielding creosote bush density / 0.007 sq km.

Figure 7: Frame captured from vegetation survey video showing a 10% wide band. Creosote bushes lying under this band were enumerated to obtain creosote bush density.

5.3 VISUAL ENCOUNTER SURVEY – LIVE ANIMALS

Visual encounter surveys are typically used for amphibians and some reptiles, but conditions required surveys to be non-invasive, and the primary animals of interest (rodents) were readily observed using the spotlighting method.

Line-transects were parallel lines running 0.8 km long in the north-south direction. A pair of transects were surveyed at 9 pm, 12 am, and 3 am each and pooled during analysis in order to observe animals that may have differing activity levels throughout the night. The transects were set 45.72 meters (150 feet) apart which was selected to be far apart enough so as to not double count or disturb animals on neighboring transects, but close enough that the data could be pooled. The observer swept a Cyclops CYC-9WS 9-Watt (240 lumens) spotlight in an arc ahead of them while searching for animals. Animals that could be positively identified were recorded, along with the perpendicular distance from the transect to where they were spotted, using a tape measure. Time and manpower allowed for each study plot to be surveyed once using the above method.

The data from each study plot were analyzed as a single transect in Distance v. 6 software (Buckland et al. 2001) and the detected species densities were modeled in the following groups: Merriam's kangaroo rats, other rodents, and reptiles and invertebrates. Animals did not occur in groups, so data were analyzed as individuals (not clustered). Prior to being analysis, density variables were pooled across sites and truncated to exclude the largest 5% of perpendicular distance values. Visibility was mostly uniform due to study plots being dominated by creosote bush scrub, except for three plots that were largely of sandy or sandy dune soil type and were sparsely vegetated.

Figure 8: Merriam's kangaroo rat observed by spotlight

Distance v. 6 models the probability of detection of objects as a function of distance from the transect to produce density estimates. The density of individuals per square unit of the area surveyed (D) is estimated with the following equation (Thomas et al. 2009 in Ellis and Bernard 2006):

$$D = \frac{n}{2\mu L}$$

where n is the number of animal "objects" detected; L is the length of line, and μ is the effective half strip-width which corresponds to the perpendicular distance from the transect line within which the number of undetected objects is equal to the number of objects that were detected beyond it. The software package considers six different models, and a model is chosen based on χ^2 goodness-of-fit tests and low Akaike's information criterion (AIC) values (Thomas et al. 2009). Here, the Half normal model with a Cosine adjustment offered the best density estimator for the data. Encounter variance rates were not calculated due to transects being pooled and analyzed as single transects.

5.4 Transect survey – Scat

Line-transect surveys for desert kit fox, coyote, and leporid scat were conducted in order to gauge habitat use across the study area. As DNA genotyping of scat samples could not be done due to limited resources, there are several caveats to these data. Scat identification error and scat persistence rates affect the data quality. However, scat was readily found and relatively easily visually identified due to the small number of carnivore species that occur in the study area, therefore a conservative attempt was made to glean any information that was forthcoming in the context of fox sightings and burrow density. While this method cannot be used to establish absence, it can provide some information about presence.

Figure 9: Kit fox scat – small and tapered

Scat was simultaneously detected during visual encounter surveys for live animals. Line-transects are described in the previous section. The search radius was limited to approximately 3 meters from the line-transect as scats were too numerous in some areas and would not allow transects to be completed on time. Kit fox scats were identified by their small, compact, tapering shape, while coyote scats were identified by their larger cylindrical shape. Black-eared jackrabbit and desert cottontail rabbit scat could be distinguished by pellet size. Upon locating scats, the distance from transect, and number of scats occurring together were recorded. The form of the scats were not recorded as decay can vary greatly due to environmental conditions and could not be analyzed. The data were analyzed using Distance v. 6 software (Buckland et al. 2001) as clustered data, and the rest of the analysis was identical to live animal density estimation as described above, yielding desert kit fox scat, coyote scat, and leporid scat density at each study plot.

5.5 HABITAT CLASSIFICATION AND DEVELOPMENT

5.5.1 Habitat classification

Habitat suitability data were obtained from a potential kit fox habitat model for the California desert developed by Penrod et al. (2012), which was classified into habitat suitability categories by Kadaba et al. (2013). The kit fox habitat suitability spatial data layer was created by South Coast Wildlands as part of the study A Linkage Network for the California Deserts (Penrod et al. 2012). This spatial data layer was created by weighting three different factors – vegetation, topography, and road density – to determine a continuous range of habitat suitability throughout the fox's range. Kadaba et al. (2013) binned these values into four different habitat categories – unsuitable, marginal, fair and good in a habitat suitability map. I used ArcMap 10.2 (ESRI 2013) to find the average the habitat suitability index value for each study plot, from the original habitat suitability map which was in the form of a raster layer. Since kit foxes were detected in all habitat categories, including unsuitable, I re-binned the habitat suitability index values occurring in the study area in order to analyze ecological relationships in varied habitat suitability, producing an ordinal variable with 5 categories.

5.5.2 Distance to development

Using a satellite image in ArcMap 10.2 (ESRI 2013), I digitized all the active anthropogenic disturbance in the area in terms of active construction, newly constructed buildings, and parcels of lands that have been razed of all vegetation in anticipation of future construction. I then calculated the linear distance between the perimeter of each study plot to the closest point on the perimeter of the nearest site of development.

5.6 STATISTICAL ANALYSIS OF HABITAT SELECTION AND THREATS

I used regression analyses to model kit fox burrow and kit fox scat density as dependent variables, and ecological and disturbance data as covariates – with the first model representing habitat occupancy, and the other, habitat use.

I assessed habitat occupancy on two different spatial scales – a home-range scale, and an individual burrow scale. For the home-range scale analysis, burrows counts were aggregated and the unit of study was each of the second plots, using a Poisson generalized linear model (GLM) with a log link. For the individual burrow scale analysis, the unit of study was discrete points, comprising the individual points were burrows were present, and a randomly generated set of points where burrows were absent (i.e. pseudoabsences), using a binomial generalized linear model with a logit link. The pseudoabsences were generated using the Create Random Points Tool in ArcMap 10 (ESRI 2011). I assessed habitat use on a single scale by analyzing scat density per sq. km at each of the 28 study plots, using another Poisson GLM.

I selected model covariates that were significant and contributed to the explanatory power of the model, and assessed the models with diagnostic statistics. I evaluated all models by examining basic diagnostic plots (Residuals vs Fitted, Normal q-q, Scale-Location, Residuals vs Leverage) and dispersion tests where appropriate.

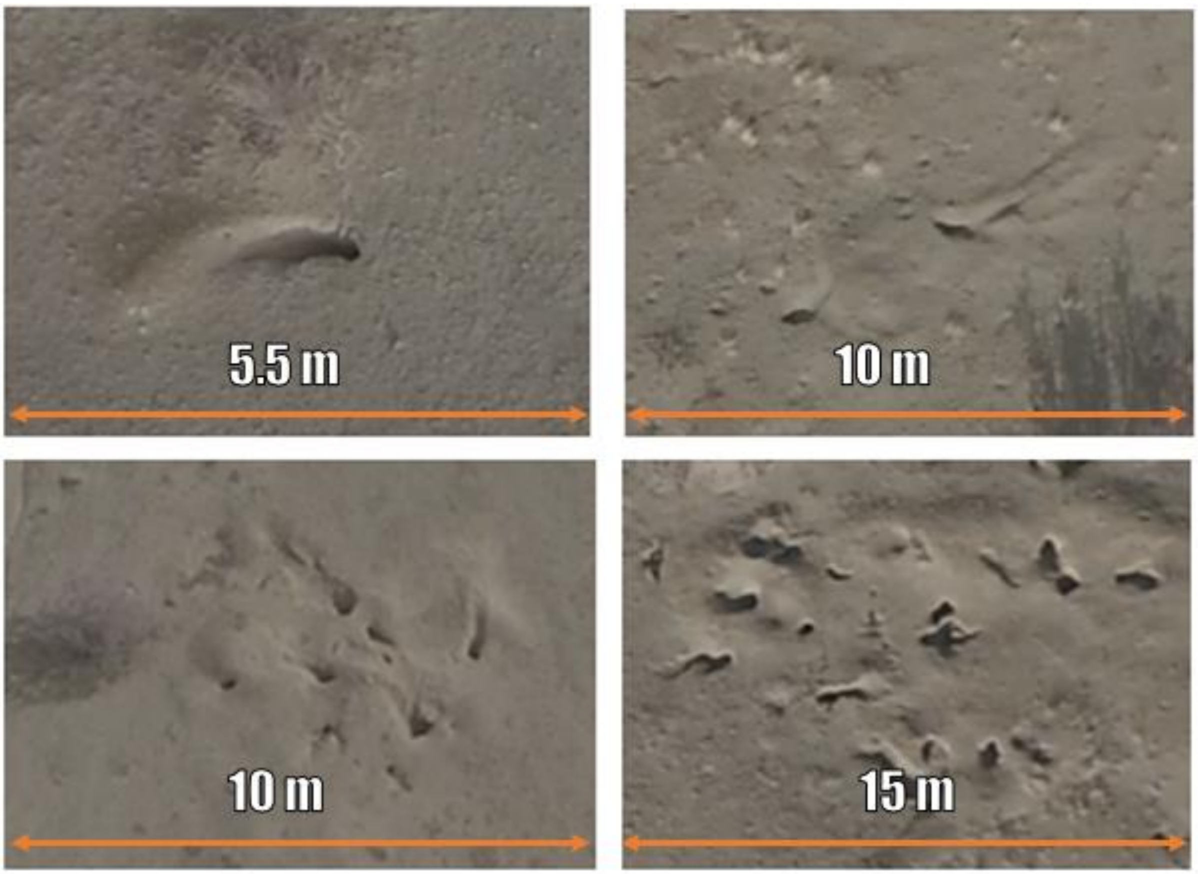
6 RESULTS

6.1 SURVEY RESULTS

Burrows

There were 60 burrows detected in total. Burrows were detected on 21 out of the 28 study plots.

Figure 10: Some examples of desert kit fox burrows and burrow complexes detected by aerial surveys



The resulting burrow density was 1.07 intact burrows/sq. km. Since the time spent on UAS-based surveys and line-transect surveys on each plot was approximately the same, I compared the detection results of both. 12 out of the 60 burrows were incidentally detected during line-transect surveys. Multiple species burrow complexes were only found on one study plot.

Kit fox burrows and presence detected via different methods are compared in figure 11 and 12..

Figure 11: Kit fox detection: Aerial vs Line-transect vs Sightings

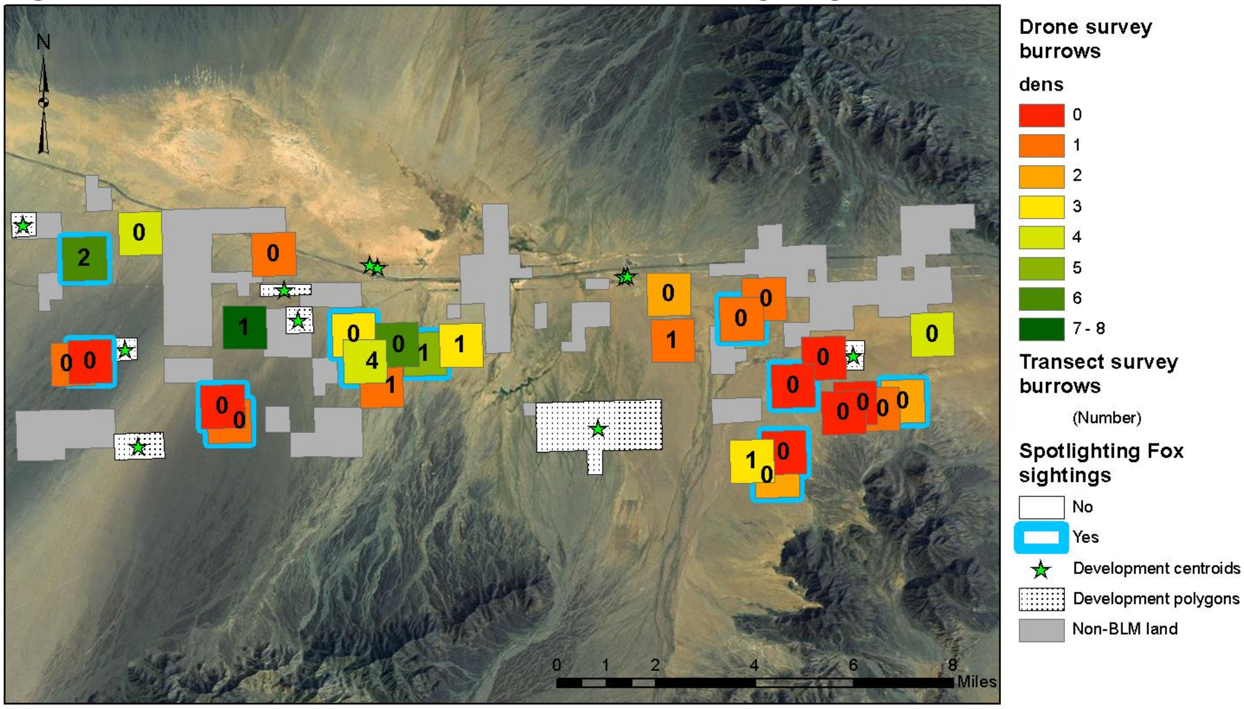
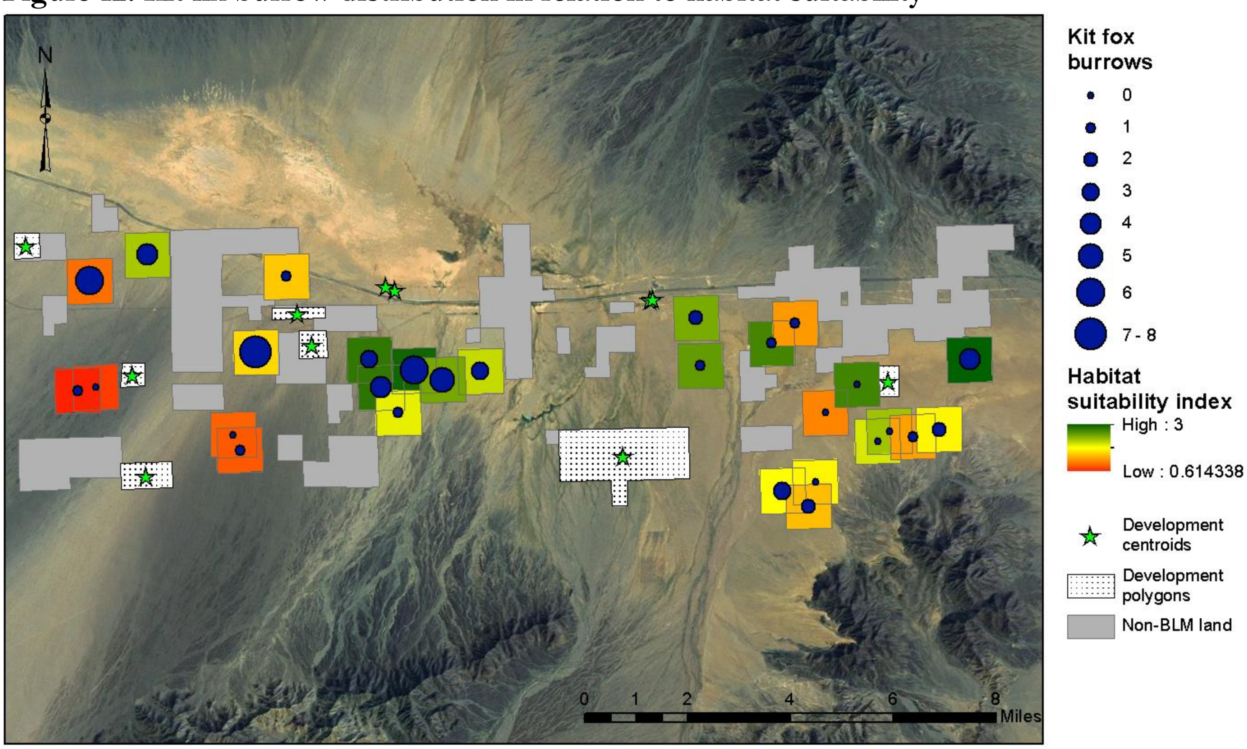


Figure 12: Kit fix burrow distribution in relation to habitat suitability



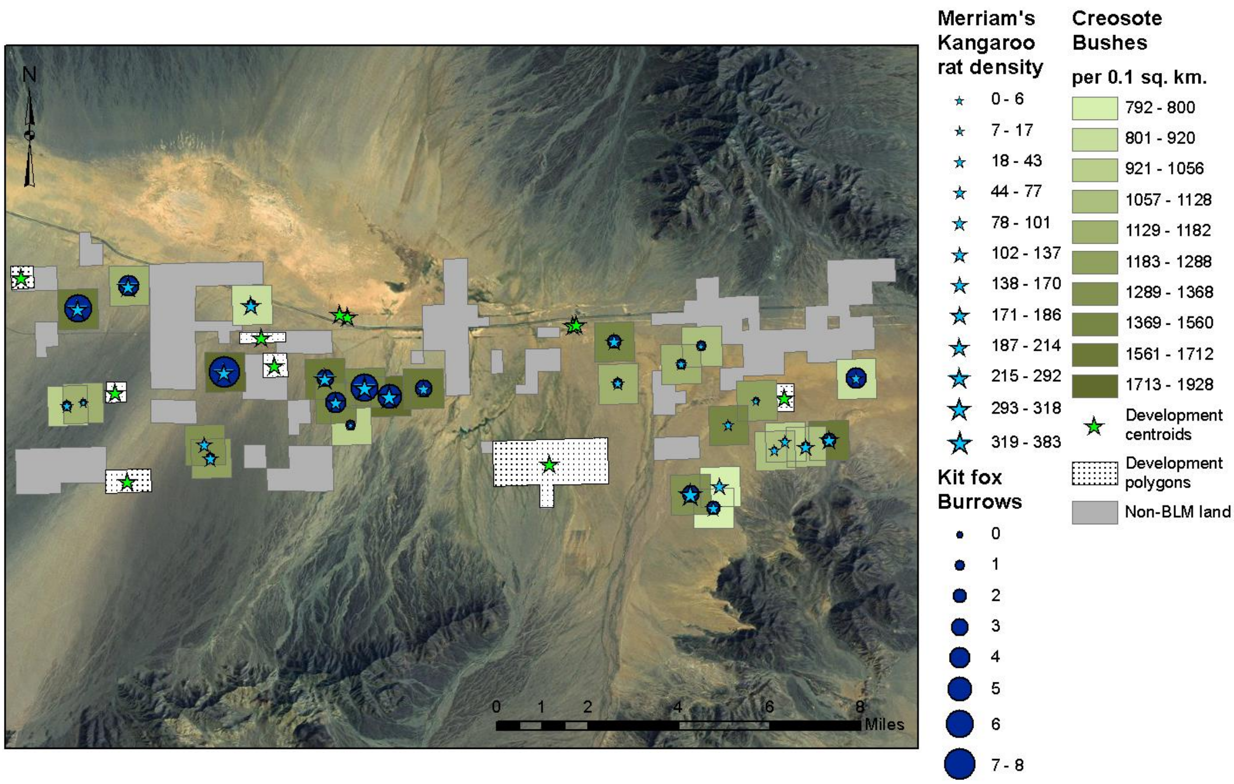
Vegetation

The average creosote bush density is 1290/0.007 sq. km. Density ranged from a minimum 792/0.007 sq. km to a maximum of 1928/0.007 sq. km. These results are summarized in figure 13.

Merriam's kangaroo rat

Merriam's kangaroo rats, the primary prey of desert kit foxes, were found on 27 of 28 plots. On plots where Merriam's kangaroo rats were present, their densities ranged from 5.85/sq. km to a maximum of 383/sq. km. These results are summarized in figure 13 below.

Figure 13: Kit fox burrows in relation to prey and vegetation

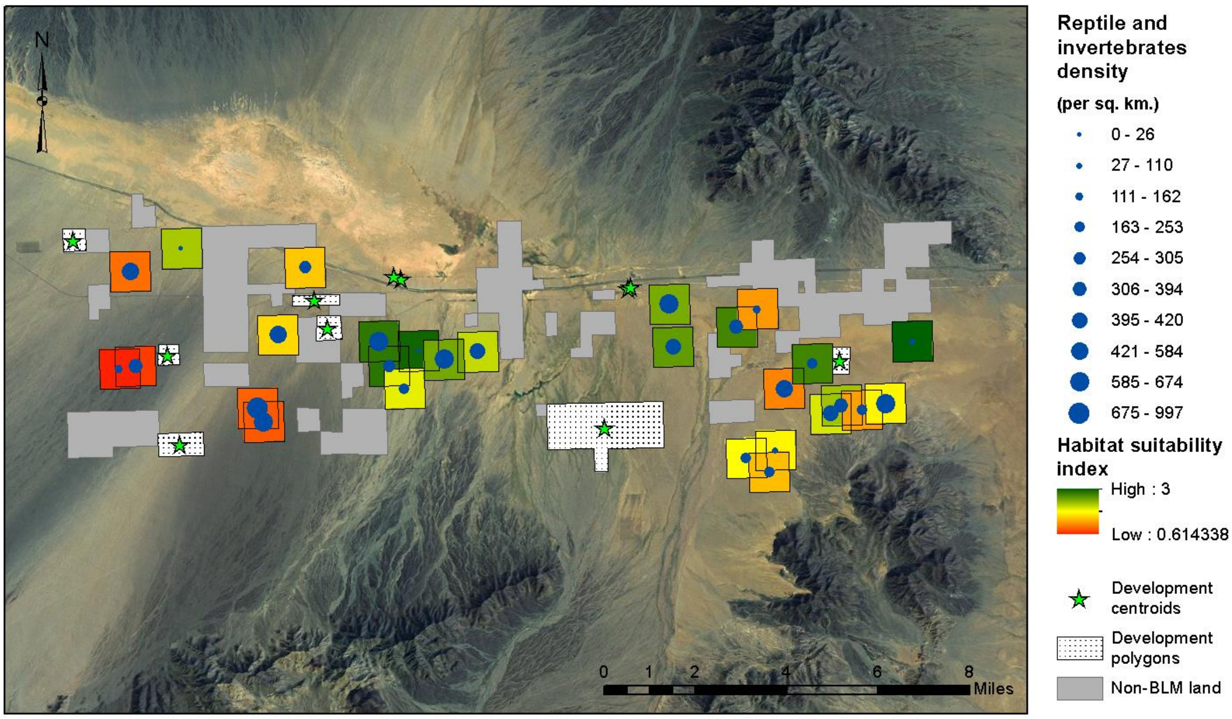


Reptiles and Invertebrates

The following reptile species were identified visual encounter surveys: long nosed leopard lizard (*Gambelia wislizenii*), side blotched lizard, zebra-tailed lizard (*Callisaurus draconoides*), desert banded gecko (*Coleonyx variegatus variegatus*), Mojave fringe-toed lizard *(Uma scoparia*), desert horned lizard (*Phrynosoma platyrhinos*), western whiptail (*Cnemidophorus tigris)*, Western shovelnose snake *(Chionactis occipitalis)*, and Colorado desert sidewinder (*Crotalus cerastes laterorepens*). The only targeted invertebrates were scorpions, solifugids and tarantulas. Smaller spiders and other small insects were not included. Reptiles and large invertebrates were completely absent from only 1 of 28 study plots.

Of the 27 plot where they were present, density ranged from a minimum of 26.2/sq. km to a maximum of 997.34/sq. km. Their density is summarized in figure 14.

Figure 14: Reptile and invertebrate density in relation to kit fox habitat suitability



Other rodents

Rodents besides Merriam's kangaroo rats were found on 23 of 28 plots. Identified rodent species were little pocket mouse, desert kangaroo rat, and desert woodrat. Their densities ranged from 8.81/sq. km to a maximum of 112.41/sq. km.

Scat density

Kit fox scat was identified on 27 of 28 study plots. Kit fox scat density ranged from a minimum of 121.7/sq. km to a maximum of 6917.45/sq. km. (Figure 15)

Coyote scat was identified on 19 of 28 study plots. Coyote scat density ranged from a minimum of 36.76/sq. km to a maximum of 1812.4/sq. km. (Figure 15)

Leporid scat was identified on 23 of 28 study plots. Both black-tailed jackrabbit and desert cottontail rabbit were detected. Leporid density ranged from a minimum of 57/sq. km to a maximum of 4029.9/sq. km. These results are summarized in figure 15 below. (Figure 16)

Figure 15: Kit fox scat density compared to coyote scat density

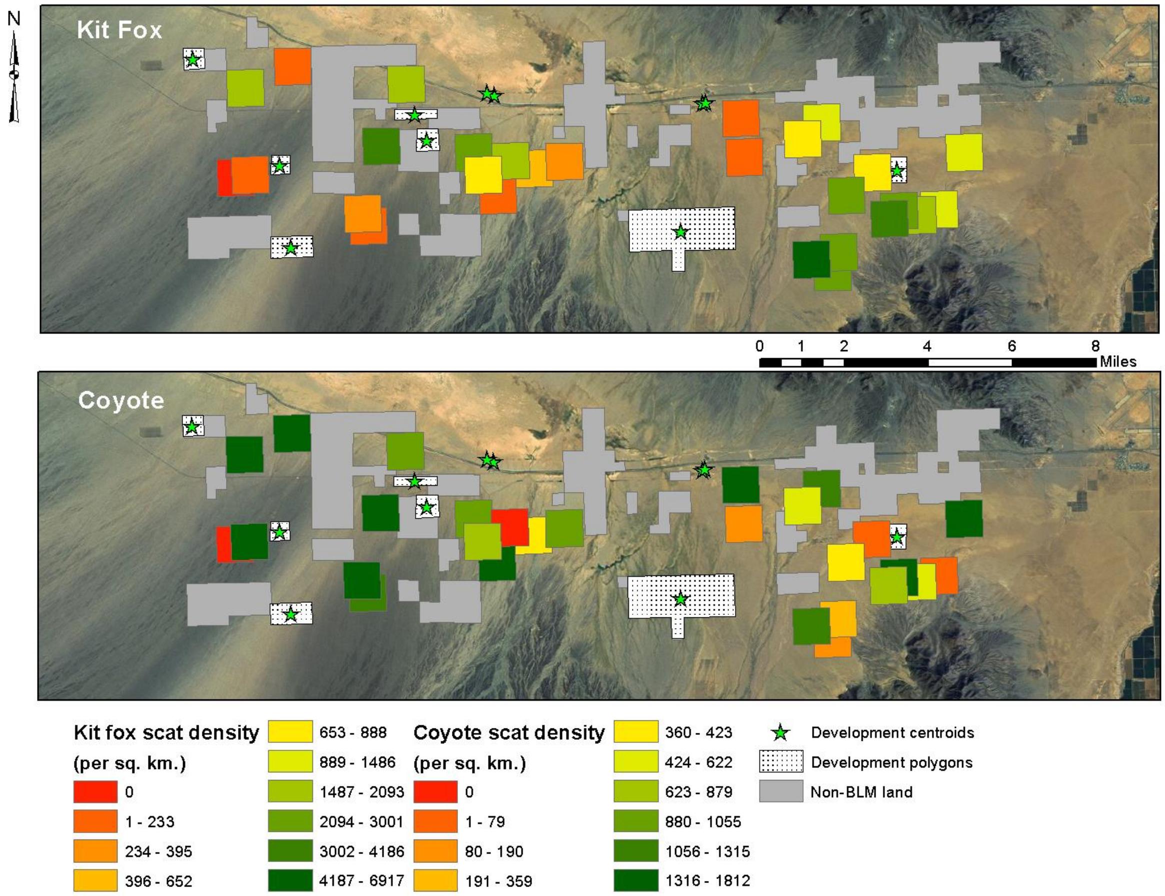
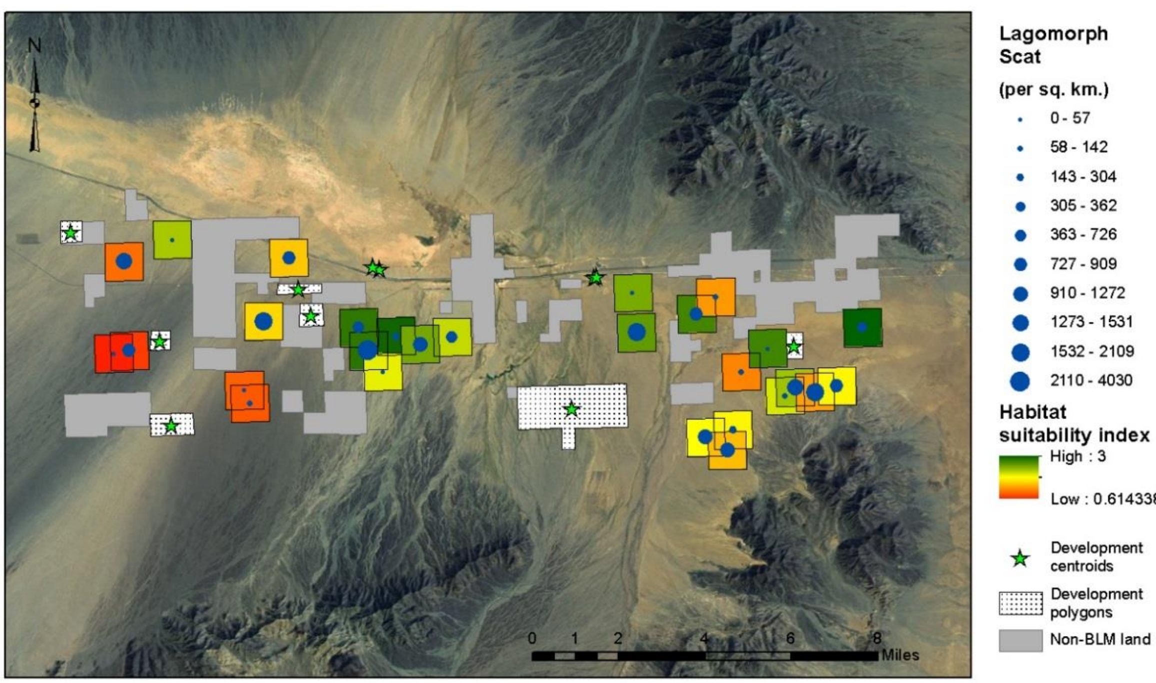


Figure 16: Leporid scat density in relation to kit fox habitat suitability



Mortalities

Incidentally observed mortalities were two unrelated sets of desert tortoise shell fragments, one kangaroo rat, and one desert kit fox.

Spatial autocorrelation of survey results

Since the perimeter of a plots was allowed to overlap another as long as its centroid did not, the spatial autocorrelation of the data were analyzed in BMEGUI 3.0.0 (Jat 2011). No significant spatial autocorrelation could be detected at any spatial range while attempting to model spatial correlation.

6.2 DISTANCE TO DEVELOPMENT

All disturbed sites closest to study plots were associated with renewable energy projects. Minimum distance to disturbance was 0 – contiguous with a disturbed site – to a maximum distance of 2.9 km.

6.3 HABITAT SELECTION AND THREATS

Habitat Occupancy gauged by burrows: Home-range scale

The chosen poisson GLM utilized burrow counts as the dependent variable and Merriam's kangaroo rat density, creosote bush density, reptile and invertebrate density, and coyote scat density as covariates. The coefficients of all covariates in the chosen model were significant at the $p<0.05$ level, and the pseudo R^2 value for the model is 0.69 ($p<0.05$). Distance to development and Habitat Suitability Index did not contribute to the model and were not included in the final model. Here, the coefficient estimates of the covariates represent the expected change in log burrow density for a one-unit increase in the covariate. These results are given in Table 2, where it can be seen that Merriam's kangaroo rat density and creosote bush density which are associated with food availability have positive relationships with burrows, while reptile and invertebrate density and coyote scat density have negative relationships with burrows – although it is likely that foxes are avoiding the habitat associated with reptiles and invertebrates and not the reptiles and invertebrates themselves.

Table 2: Poisson Generalized Linear Model of habitat occupancy gauged by desert kit fox burrows, where response variable = Count of burrows per plot.

	Estimate	**Pr (>|z|)**
Intercept	-1.587	0.01566 *
Merriam's Kangaroo rat density	0.004	0.02825 *

Creosote bush density	0.004	0.00855 **
Reptile and invertebrate density	-0.002	0.01802 *
Coyote scat density	-0.0004	0.04483 *
R^2 – 0.69, p=3.4e-08 ($p<0.05$)		
Significance codes: 0 '***' 0.001 '**' 0.01 '*'		

Habitat Occupancy gauged by burrows: Individual burrow scale

The chosen binomial GLM utilized burrow presence or absence as the dependent variable and creosote bush density, reptile and invertebrate density, coyote scat density, distance to development, and Habitat Suitability Index as covariates, which differs from the previous model with the additional last two covariates. The coefficients of all covariates in the chosen model were significant at the $p<0.05$ level, and the pseudo R^2 value for the model is 0.14 ($p<0.05$), which is much lower than the previous model. Here, the coefficient estimates of the covariates represent the expected change in log burrow density for a one-unit increase in the covariate. Merriam's kangaroo rat density did not contribute to the model and was not included in the final model. These results are given in Table 3, where it can be seen that creosote bush density, reptile and invertebrate density, coyote scat, had relationships with the same sign (positive or negative) as the previous model with the log odds of burrow presence. In addition, increasing distance from development had a positive relationship with burrow presence, and increasing habitat suitability had an unexpected negative relationship with burrow presence. Diagnostic plots did not indicate any issues with the fit of the model.

Table 3: Binomial Generalized Linear Model of habitat use gauged by desert kit fox presence, where response variable = Point presence or pseudoabsence

	Estimate	**Pr (>|z|)**
Intercept	-5.132	5.90e-10 ***
Creosote bush density	0.005	4.49e-12***
Reptile and Invertebrate density	-0.005	1.61e-07***
Coyote scat density	-0.001	0.00248**
Distance to development	47.942	0.00655**

Habitat Suitability Index	-1.337	4.56e-08***
R^2 – 0.14, p=3.5e-12 ($p<0.05$)		
Significance codes: 0 '***' 0.001 '**' 0.01 '*'		

Habitat Use gauged by burrows

The chosen poisson GLM utilized burrow counts as the dependent variable and Merriam's kangaroo rat density, creosote bush density, reptile and invertebrate density, coyote scat density, distance to development, and Habitat Suitability Index as covariates. The coefficients of all covariates in the chosen model were significant at the $p<0.05$ level, and the pseudo R^2 value for the model is 0.14 ($p<0.05$), which is once again low especially when compared to the first model. As seen in the results given in Table 4, Merriam's kangaroo rat density, coyote scat density, and habitat suitability index have coefficients with the same sign as those appearing in the habitat occupancy models (notably, the same unexpected negative relationship between habitat suitability and kit fox sign). However creosote bush density and reptile and invertebrate density had positive coefficients while distance to development had a negative coefficient in contrast with habitat occupancy.

Table 4: Poisson Generalized Linear Model of desert kit fox habitat use, where response variable = Kit fox scat density per plot

	Estimate	**Pr (>|z|)**
Intercept	8.178e+00	<2e-16 ***
Merriams's Kangaroo rat density	3.451e-03	<2e-16 ***
Creosote bush density	-1.773e-03	<2e-16 ***
Reptile and Invertebrate Density	6.832e-04	<2e-16 ***
Coyote scat density	-4.874e-02	8.09e-05 ***
Distance to development	-2.758e+01	<2e-16 ***
Habitat Suitability Index	-0.0004743	<2e-16 ***
R^2 – 0.14, p=3.4e-08 ($p<0.05$)		
Significance codes: 0 '***' 0.001 '**' 0.01 '*'		

7 DISCUSSION

Habitat selection in an impact assessment framework

As stated earlier, threats from large-scale industrial solar development to the desert kit fox such as habitat loss, degradation, fragmentation, loss of connectivity, reduced ability for movement, increased competition and depredation, have not been adequately evaluated.

The results of the statistical analyses in this study indicate desert kit fox habitat occupancy gauged by presence of burrows varies considerably from habitat use gauged by scat density. Thus, parameters of models of habitat suitability and habitat connectivity may be very different and must be considered separately during land use planning. The Habitat Suitability Index based on widely accepted desert kit fox ecology was strongly contradicted by regression results and individual observations, including burrows found in areas deemed "unsuitable". Another significant result that warrants further study is the fact that distance to development had a negative relationship with burrow presence, but a positive relationship with scat density, implying development may reduce burrowing suitability but may attract foxes which exposes them to the risks associated with human presence.

Coyote presence negatively impacted desert kit fox habitat selection in all three models, which suggests that the potential subsidization of coyote populations due to increased water availability associated with land development is an important factor that remains unevaluated.

Since habitat selection models do not agree, coyotes may be encouraged by land development, and habitat suitability indices are not reliable indicators of habitat selection, both existing habitat models and the assumptions of cumulative impacts of land development are inadequate for the assessment of the impacts of large-scale renewable energy development in desert kit fox habitat.

Scat density assessment

The first caveat occurs in the identification of scat. Small, dense, distinctly tapered kit fox scat is distinguishable from larger, cylindrical coyote scat. Vegetation laden gray fox scat was rarely observed, and counts were not analyzed. The other carnivores known to occur in the area – bobcats and badgers – were not detected during scat surveys and not expected to be confused with scat from the canine species that were detected (A single potential badger scat was detected during surveys). In conclusion, identification error of kit fox and coyote scat is a possibility, but not expected to be significant.

Persistence of scat is another factor that interferes with the assessment of habitat use through density of scat. One study showed that the median survival of coyote scat in the Sonoran desert is 11 days annually, and just 4 days from June through July (Sanchez et al. 2010). Persistence would also be affected by habitat type.

Mortality

There was no background avian mortality detected despite several times the survey effort used at renewable energy sites. There is currently a lack of information on background avian mortality in this region that can provide context to the avian deaths found at newly constructed solar energy projects. At the Genesis Solar Project, 2.5 km away from the Northern perimeter of the study area, more than 60 dead birds were found in August, representing the cumulative mortalities around the same time as our line-transect surveys from June through July. Cases of avian mortality were incidental discoveries noted by project staff while going about other duties, and not during systematic mortality surveys (Genesis Solar, LLC, 2013), so it is possible that the true mortality rate is higher. An analysis of solar energy facilities in Southern California reported that a facility experiencing avian mortalities may attract insects and insect-eating birds which are incapacitated by solar flux injury, and attract predators (Kagan et al. 2014). The subsidization of predators may impact desert kit fox populations, as well as attract kit foxes and expose them to human disturbance.

Sherman trapping, Pitfall trapping, Camera trapping, Spotlighting

There are few established protocols with an upper limit of temperature for small rodent trapping in desert landscapes. One protocol for identification of San Joaquin kangaroo rats gives an upper limit of 105°F (USFWS 2013). This temperature was crossed on several days during June and July. Heavy rain was also unpredictable throughout the summer which made pitfall trapping unsafe even with drains drilled into buckets. Small mammal trapping was attempted using Sherman Extra-Large Kangaroo Rat live folding traps (7.6 x 9.5 x 30.5 cm; HB Sherman Traps Inc. Tallahassee, FL). Steady captures occurred only from day 3 onward, and inclement weather would almost always interrupt a full 5 day cycle. Capture rates were also quite low in the area. Over one night with 100 open traps, captures were usually in the single digits. Our visual encounter surveys yielded substantial counts, and would probably be robust if they were repeated more than once and averaged. I concluded that non-invasive methods are most reliable in this desert landscape during the summer.

Scent-baited camera traps frequently failed due to intense heat and user error. Since the camera-trapping schedule could not be maintained due to these failures, the results were not analyzed, but it is interesting to note that foxes were detected on camera on some plots where burrows were not found, and not detected over 7 nights of camera trapping on plots were burrows did occur.

Although leporid scat was detected on 23 of 28 plots and coyote scat was detected on 19 of 28 plots, only a few desert kit foxes were detected by the spotlighting method, while no leporids or coyotes eyeshine was ever detected. Spotlighting does not seem to be an effective method for the detection or enumeration of leporids, coyotes, and desert kit foxes in this area.

Applications of UASs

Aerial survey by UAS was well suited to the landscape due to its low vegetation, flat topography, and lack of human presence. Vegetation did not occlude any objects of interest. Aerial surveys were consistently more sensitive to desert kit fox presence than any other attempted method per unit effort in time.

Once weather limits and a maintenance routine was established, no mechanical malfunctions occurred. The presence of the UAS overhead did not appear to disturb animals. Common bushes, trees, and large grasses, could be identified, while smaller herbs and annuals could not be identified.

Electronic controllers were very sensitive to heat and direct sunlight, and the magnetometer compass was also sensitive to direct sunlight. Commercial UASs are probably not well suited to flights above solar projects for research purposes due to the concentrated heat and light.

Invasive species

Sahara mustard and non-native grasses were common in areas around energy development areas and roads. I was unable to quantify invasive species on a landscape level with the methods used in this study due to their small size. It is possible that these species affect habitat selection by desert kit foxes due to changes in visibility for hunting, as well as prey availability. Future studies should attempt to assess the impact of invasive vegetation species driven by landscape disturbance on desert kit foxes in order to determine the true cumulative environmental impact of development in their habitat.

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